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THRESHOLD ADAPTATION USING NON-LINEAR OPTIMIZATION FOR TRANSMISSION RATE ENHANCEMENT IN COOPERATIVE SPECTRUM SENSING

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ABSTRACT

In this paper we have studied the threshold adaptation for energy based spectrum sensing in cognitive radio using non-linear optimization. Several methods to decide the threshold have been proposed in the literature such as fixed threshold, double threshold and adaptive threshold etc. Instead of using these methods to decide threshold in energy detection, an adaptive threshold has been proposed by researchers that varies according to the Signal to Interference plus Noise Ratio (SINR) experienced at Secondary User (SU) receiver to maximize the average transmission rate of secondary user while keeping the average probability of missed detection within predefined level. However in the existing scheme, the threshold is considered as a linear function of SINR to maximize the average transmission rate of secondary user. It has been observed that the use of a non-linear function in place of a linear one produces better performance. In this paper we use non-linear increasing function to find threshold in terms of SINR for cooperative spectrum sensing in cognitive radio. The simulation results on MATLAB show that the average transmission rate can be increased in cooperative spectrum sensing in comparison to the non-cooperative spectrum sensing. Also, in cooperative scenario, the proposed non-linear policy function yields significantly better results than the linear policy function in low SNR conditions.

Keywords: Cognitive Radio (CR), Cooperative Spectrum Sensing (CSS), Energy Detection, Threshold Adaptation.

I. INTRODUCTİON

The field of wireless communication has witnessed a tremendous growth in the recent years. The growth is still continuing due to which the demand of frequency spectrum band is exponentially increasing. As the wireless communication technology is developing, the number of users is also increasing which further increases the demand of frequency spectrum bands. In wireless communication technology ideally we have infinite spectrum bands but due to physical limitations of devices we can use only some limited spectrum bands. Out of these usable bands some are licensed and some are un-licensed for different wireless communication services. In a survey made by Federal Communications Commission (FCC) it has been found that most part (nearly 70%) of the licensed spectrum is not utilized in US [1]. Another survey made by FCC reveals that the maximum spectrum occupancy is nearly 13.1% from 30 MHz to 3 GHz in New York City [1]. Finally it has been concluded that the most part of the licensed spectrum band remains unused most of the time and at most of the places. Thus we find that licensed bands are under-utilized while at the same time un-licensed bands are over-utilized.

The utilization of spectrum can be increased by permitting a SU to use a licensed band whenever the primary user (PU) is not present. Cognitive radio has been proposed to improve the spectrum utilization. It is an intelligent software defined radio (SDR) which continuously observes its surroundings and changes its parameters according to surrounding conditions. Cognitive radio is able to utilize spectrum holes for SUs without any harmful interference to the PU by sensing and adapting the surrounding conditions. Thus the spectrum sensing is the first and very important task of a cognitive radio to know the status of PU in a particular licensed spectrum band. There are several spectrum sensing techniques available but energy detection method is mostly used for spectrum sensing in cognitive radio because it does not require any prior information about the primary user's signal and it is very simple [1]. The working performance of energy detection method mostly depends on how efficiently the threshold energy (λ) has been decided to which the measured energy of sensed signal is compared for taking final decision about the status of PU. One major challenge to implement spectrum sensing is hidden node problem, which occurs due to shadowing and multipath fading.

Cooperative spectrum sensing is a powerful solution of hidden node problem. In cooperative spectrum sensing, two or more than two CRs make their individual decisions about the status of PU by sensing the licensed spectrum but it is not their final decision. To make the final decision all participating CRs send their individual decisions to a fusion center (FC). Fusion center fuses all individual decisions using hard or soft combining technics and makes a final decision for all CRs [1].

Several methods are available in literature to find the value of threshold energy. In general the target performance metrics of spectrum sensing such as *probability of missed detection* (P_m) or *probability of false alarm* (P_f) is used to decide the threshold value in energy detection. The concept of fixed threshold and its limitation due to random behavior of noise is discussed and a method is also proposed to find threshold value by sensing some particular number of samples for achieving certain level of performance in [2] & [3]. A method to find lowest threshold while keeping $P_f(\lambda)$ and $P_m(\lambda)$ below predefined level by using dynamic threshold adaptation is proposed in [4]. Fixed threshold and double threshold methods are described in [5]. In [6] a method has been proposed by authors to find best threshold value for known SINR which minimizes the total error in case of cooperative spectrum sensing. The works reported in [7] and [8] describe the tradeoff between throughput of secondary user and sensing time and, the effect of noise power estimation on energy detection, respectively. An idea of adaptive threshold control has been given in [9] and [10]. In these papers it has been shown that the threshold (λ) should be an increasing function of SINR (γ) for achieving maximum throughput. Further a linear relation between threshold (λ) and SINR (γ) has been assumed in [9] and [10]. In our previous work we have shown that a non-linear relation is better than linear relation for achieving maximum throughput of secondary user in case of single cognitive radio [11].

In this paper we use non-linear relation between threshold (λ) and SINR (γ) to maximize the average transmission rate of SU in cooperative spectrum sensing while keeping the average probability of missed detection within predefined level. We compare our results with the previous results of [11] which have been obtained in case of non-cooperative spectrum sensing.

Remaining part of this paper is organized as follows. In section II, the system model is given. In section III, the adaptive threshold control for MAR is discussed which contains the MAR problem along with non-linear policy function. The key components which are required to solve the MAR problem are listed in section IV whereas all numerical results and comparisons are presented in section V. Finally, the overall findings of the present work are concluded in section VI.

II. SYSTEM MODEL

A time slotted cognitive radio system having one primary user and *K* secondary users is assumed here. All users transmit their data using constant power. For spectrum sensing at the beginning of each time slot, energy detection method is used by all SU's transmitters. Any one of the SU's transmitters will start transmitting its data if and only if the decision is H_0 i.e. PU is absent. In our model the conditions and parameters for all SUs are identical and thus all necessary values obtained for one SU are also applicable for other SUs as well. The activity of the PU is modeled by using two-state discrete-time Markov process. As given in [10], the probability that the channel is in busy state ($Pr\{H_1\}$)or in idle state ($Pr\{H_0\}$)can be calculated as

$$\begin{cases} Pr\{H_1\} = \dfrac{\alpha}{\alpha + \beta} \\ Pr\{H_0\} = \dfrac{\beta}{\alpha + \beta} \end{cases} \qquad (1)$$

Here α & β are traffic birth rate and traffic death rate, respectively. The wireless channels existing between all users are considered as Rayleigh fading channel with additive white Gaussian noise (AWGN) of zero mean and unit variance. Following the model of [10], the SINR (γ) at the secondary user's receiver can be calculated as:

$$\gamma = \begin{cases} \gamma_{H_0} = \gamma_{sr}, & \text{no PU transmission;} \\ \gamma_{H_1} = \dfrac{\gamma_{sr}}{1+\gamma_{pr}}, & \text{otherwise.} \end{cases} \qquad (2)$$

Here γ_{sr}, γ_{pr} and γ_{ps} are the instantaneous SNR from SU's transmitter to SU's receiver, from PU's transmitter to SU's receiver and from PU's transmitter to SU's transmitter, respectively.

In our model we assume that the value of SINR (γ) remains constant in the same time slot and SU's receiver detects and sends the value of (γ) to SU's transmitter at the starting of each slot without any error. The final decision of spectrum sensing is taken by applying OR rule at fusion center.

III. ADAPTIVE THRESHOLD CONTROL FOR MAR

If the system bandwidth is B then the Maximum Average Rate (MAR) problem can be given by (3) and (4) [9, 10].

Maximize

$$\left(\bar{R}_{H_0} + \bar{R}_{H_1}\right). \qquad (3)$$

subject to

$$\int_0^\infty P_M\left(\lambda(\gamma_{H_1})\right) f_{H_1}(\gamma_{H_1}) d\gamma_{H_1} = \int_0^\infty \left(1 - P_D\left(\lambda(\gamma_{H_1})\right)\right) f_{H_1}(\gamma_{H_1}) d\gamma_{H_1} \le \bar{P}_M. \quad (4)$$

where

$$\bar{R}_{H_0} = \frac{B\beta}{(\alpha+\beta)\Gamma(M)\bar{\gamma}_{sr}} \int_0^\infty log_2(1+\gamma_{H_0}) \times \left(1 - P_F\left(\lambda(\gamma_{H_0})\right)\right) e^{-\frac{\gamma_{H_0}}{\bar{\gamma}_{sr}}} d\gamma_{H_0}. \quad (5)$$

and

$$\bar{R}_{H_1} = \frac{B\alpha}{\alpha+\beta} \int_0^\infty log_2(1+\gamma_{H_1}) \left(1 - P_D\left(\lambda(\gamma_{H_1})\right)\right) \times$$
$$\left[\frac{1}{(\bar{\gamma}_{pr}\gamma_{H_1} + \bar{\gamma}_{sr})} + \frac{\bar{\gamma}_{sr}\bar{\gamma}_{pr}}{(\bar{\gamma}_{pr}\gamma_{H_1} + \bar{\gamma}_{sr})^2}\right] e^{-\frac{\gamma_{H_1}}{\bar{\gamma}_{sr}}} d\gamma_{H_1}. \quad (6)$$

Here, $P_M(\lambda)$, $P_D(\lambda)$, $P_F(\lambda)$ and $\bar{P}_M$ are probability of missed detection, probability of detection, probability of false alarm and average probability of missed detection for cooperative spectrum sensing, respectively.

3.1 Non-Linear Policy Function

As explained in [9, 10], the threshold λ(γ) should be an increasing function of SINR (γ) observed at SU's receiver to get maximum average transmission rate of SU. This fact can also be seen by (2). Here we have chosen threshold λ(γ) as a non-linear increasing function of SINR (γ) given in (7) because this function is better than the linear function [11].

Let,

$$m(\gamma) = a\gamma^2 + b\gamma + c,$$

$$\lambda(\gamma) = \begin{cases} m(\gamma), & m(\gamma) \ge 0; \\ 0 & otherwise. \end{cases} \quad (7)$$

Here *a*, *b* and *c* are the parameters whose values are to be obtained by solving the MAR problem and $m(\gamma)$ is an intermediate constant. The values of all parameters can be obtained by solving the MAR problem. Once the appropriate values of *a*, *b* and *c* are obtained, we can make an adaptive threshold which varies with the instantaneous variation of SINR(γ) and makes CR more environment-adaptive.

IV. KEY COMPONENTS IN MAR

To solve MAR problem given in (3) and (4), we require formulation of several key components. These key components include $P_m(\lambda)$, $P_f(\lambda)$ and the PDFs of γ_{H_1} and γ_{H_0} denoted as $f_{H_1}(\gamma_{H_1})$ and $f_{H_0}(\gamma_{H_0})$, respectively. All these components for single user are given in [10].

In our model we are using cooperative spectrum sensing to make final decision about the status of PU using OR rule. If we assume that the values of $P_m(\lambda)$, $P_f(\lambda)$ for all individual cognitive radios are identical then the overall probability of missed detection ($P_M(\lambda)$) and probability of false alarm ($P_F(\lambda)$) for OR rule in cooperative spectrum sensing can be given as:

$$P_M(\lambda) = (P_m(\lambda))^K \quad (8)$$

and

$$P_F(\lambda) = 1 - \left(1 - P_f(\lambda)\right)^K \quad (9)$$

Here *K* is the number of SUs participating in cooperation. It is notable that the probability of detection ($P_D(\lambda)$) in cooperative spectrum sensing can be given as:

$$P_D(\lambda) = 1 - P_M(\lambda) \qquad (10)$$

By solving equations (3) & (4) using equations (5) to (10), we can easily find the values of *a*, *b* and *c* which maximize the average transmission rate of SU while keeping the probability of missed detection within pre-defined level. By using these values of *a*, *b* and *c* we can regulate the threshold with instantaneous change in SINR occurring due to change in environmental conditions.

4.1 Implementation Issues and General Discussion

It is not an easy task to find the best relation between λ and γ for maximizing the average transmission rate of SU. In this paper, we take a non-linear relation between λ and γ as given in (7) on the basis of the result obtained in [11] which shows that this non-linear relation is better than the linear relation. We use MATLAB optimization (i.e., the MATLAB fmincon command) to solve the MAR problem and find the values of {*a*, *b*, *c*}. If the values of all parameters such as {α, β, $\bar{\gamma}_{sr}$, $\bar{\gamma}_{pr}$ and $\bar{\gamma}_{ps}$} are already known then we can find optimized values of {*a*, *b*, *c*}. It has been pointed out in [10] that the system parameters {α, β, $\bar{\gamma}_{sr}$, $\bar{\gamma}_{pr}$ and $\bar{\gamma}_{ps}$} may change with time but these changes will occur after much longer time than the real time change in γ because parameters are taken as mean values.

V. NUMERICAL RESULTS

All the simulations are performed on MATLAB. In simulation we fix the PU's traffic birth rate, α = 0.5, traffic death rate β = 0.7, and the bandwidth B= 100 KHz. The SNRsγ_{sr}, γ_{pr} and γ_{ps} are assumed to be iid having exponential distribution with means$\bar{\gamma}_{sr}$, $\bar{\gamma}_{pr}$ and $\bar{\gamma}_{ps}$, respectively. For simulation, we set $\bar{\gamma}_{pr}$= $\bar{\gamma}_{ps}$= 10dB and change the value of $\bar{\gamma}_{sr}$from 10 dB to 30 dB. The maximum limit for average probability of missed detection in cooperative spectrum sensing is fixed as 0.05 (i.e.$\bar{P}_M = 0.05$). The number of SUs participating in cooperative spectrum sensing K=5.

We simulate the energy detector with adaptive threshold in two different scenarios, first one is for single cognitive radio and second one is for K=5 CRs performing cooperative spectrum sensing using OR rule. In both conditions, we optimize the values of a, b and c to find maximum transmission rate of SU while keeping average probability of missed detection within 0.05. We investigate three parameters in our work that are $\bar{R}_{H_0}$, $\bar{R}_{H_1}$ and$\bar{P}_M$.

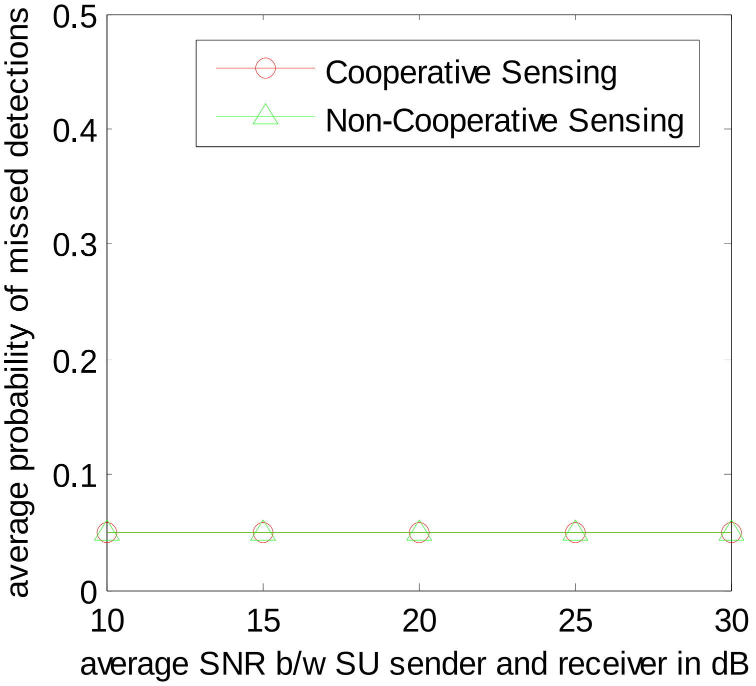

Fig.1. Average missed detection probabilities with $\bar{\gamma}_{sr}$.

Fig.1 shows the graph between $\bar{P}_M$ and quality of channel denoted as $\bar{\gamma}_{sr}$. In this Fig., we can see that the value of $\bar{P}_M$ never exceeds 0.05 in both cases (i.e. cooperative and non-cooperative spectrum sensing) as desired.

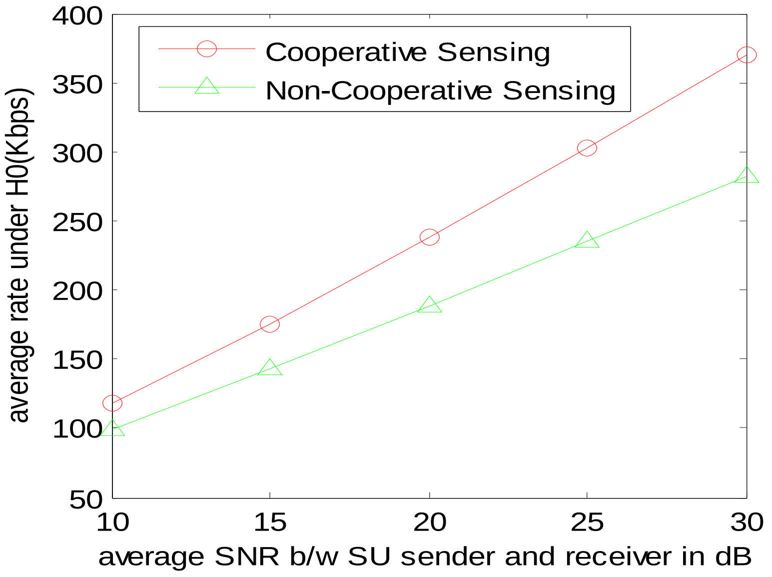

Fig.2. Average transmission rate of SU in H_0.

The plot of $\bar{R}_{H_0}$ with channel quality ($\bar{\gamma}_{sr}$) is shown in Fig.2. From this Fig., it can be observed that the average transmission rate ($\bar{R}_{H_0}$) in cooperative spectrum sensing is greater than the $\bar{R}_{H_0}$ in non-cooperative spectrum sensing and the difference between $\bar{R}_{H_0}$ of cooperative and non-cooperative sensing increases with increase in SNR.

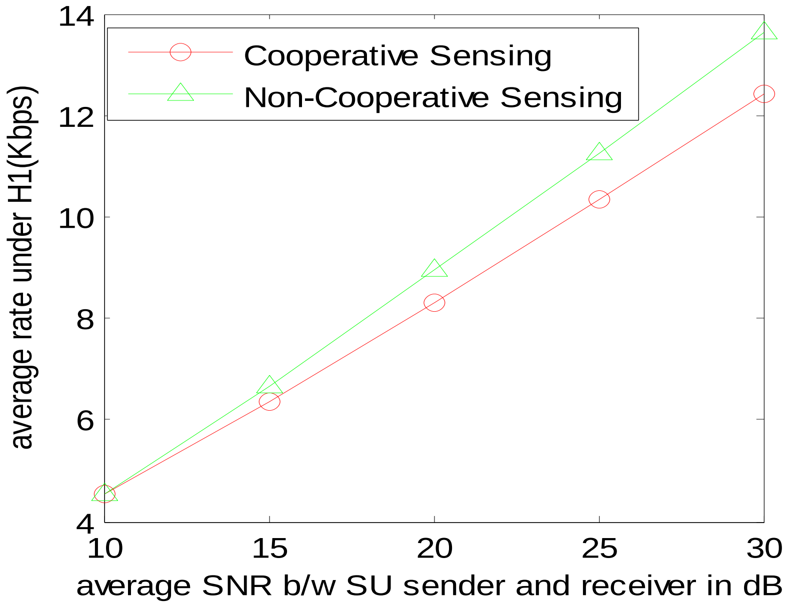

Fig.3. Average transmission rate of SU in H_1.

Fig.3 shows the plot of $\bar{R}_{H_1}$ with channel quality. Here we see that the value of $\bar{R}_{H_1}$ in cooperative spectrum sensing is slightly less than $\bar{R}_{H_1}$ in non-cooperative spectrum sensing for all values of $\bar{\gamma}_{sr}$. This can be attributed to more reliable sensing in case of CSS.

By observing fig.2 and fig.3 we find that the average transmission rate of SU when PU is absent denoted as $\bar{R}_{H_0}$ is much greater than the average transmission rate of SU when PU is present ($\bar{R}_{H_1}$).

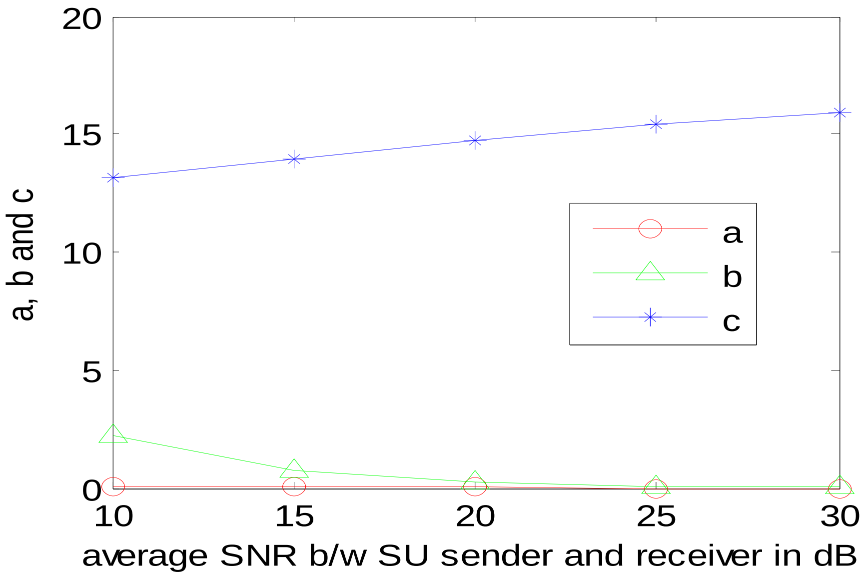

Fig.4. Optimized a, b and c vs. $\bar{\gamma}_{sr}$.

The variation in the values of *a*, *b* and *c* with $\bar{\gamma}_{sr}$ is shown in Fig.4. for cooperative spectrum sensing.

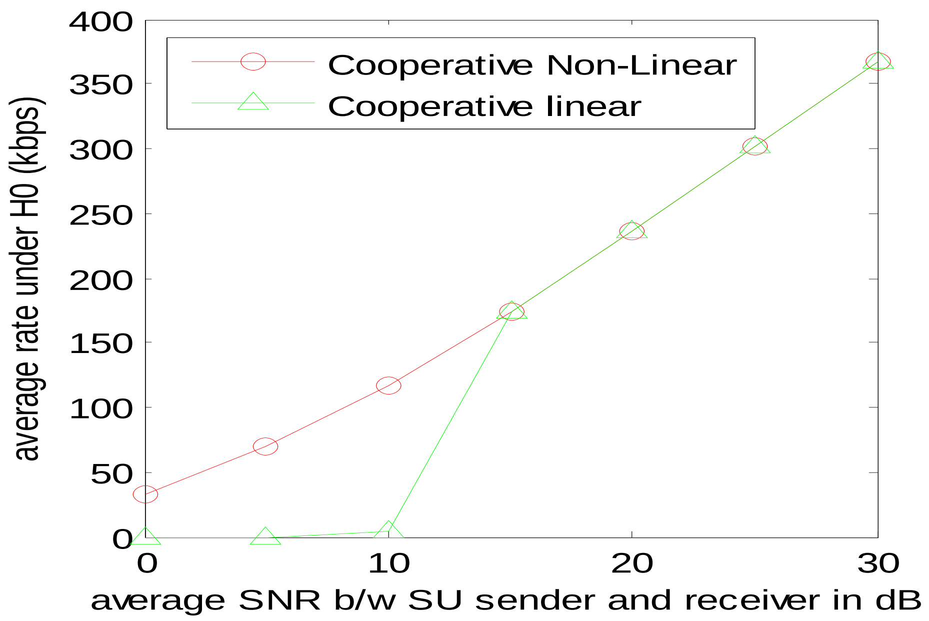

Fig.5. Comparison Between Cooperative Non-Linear and Cooperative Linear

We also compare our results which are obtained in CSS assuming non-linear relation between λ and γ with the results obtained in CSS assuming linear relation ($\lambda(\gamma) = p\gamma + q$) between λ and γ. Fig.5 shows that in low SNR (bellow 15 dB} the average transmission rate of cooperative linear method under H_0 is very less than the cooperative non-linear method. Thus our proposed non-linear relation with CSS is well suited for low SNR values in comparison with linear relation. At higher SNRs the average rates achieved by using linear as well as non-linear relations are almost same.

VI. CONCLUSION

We have presented a threshold adaptation scheme for energy based cooperative spectrum sensing in cognitive radios. A non-linear policy function is used to regulate the value of threshold with the SINR observed at SU's receiver. To achieve maximum average transmission rate of secondary user while satisfying the average probability of missed detection constraint, we formulated a MAR problem which is solved by using MATLAB for cooperative spectrum sensing. We find that, in general, for the same probability of missed detection constraint, SU's overall average transmission rate in cooperative spectrum sensing is greater than that in non-cooperative spectrum sensing. It is also shown that the proposed CSS with non-linear policy function is significantly better in highly noisy conditions than CSS with linear policy function.

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